Intellectual Property and Licensing in the Commercial Space Age

Daniel Broderick
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Dr.
Pasadena, CA 91109
Daniel.f.Broderick@jpl.nasa.gov

Abstract— **The commercial space industry is undergoing a paradigm shift from the time when governments and very large space companies dominated the industry. A confluence of laws allowing commercial space companies to operate in unprecedented ways, new technologies enabling new commercial space applications, and an influx of risk capital has drastically changed the space industry landscape. As small and medium-sized companies enter the commercial space realm, they will seek a competitive advantage, and universities and the NASA space centers are positioned to offer such advantages. The commercial space industry has recently become an active area of technology partnering and licensing, even for technologies that have experienced poor licensing performance in the past. The Jet Propulsion Laboratory is seeing unprecedented technology transfer activity in the areas of spacecraft navigation, mission design, space antennas, thrusters, radio occultation, and specialized satellites. Intellectual property rights and partnering play a crucial role in the ability of the private sector to invest in these technologies and to drive space technologies forward. Participants in this burgeoning field seek the most cutting-edge innovations to attain a competitive advantage, and it is crucial for those in the university and public sector to gain an understanding of the market forces that are driving the commercial space business.**

TABLE OF CONTENTS

1. INTRODUCTION

On July 29, 1958 President Eisenhower signed the National Aeronautics and Space Act of 1958 [1], which established the National Aeronautics and Space Administration (NASA). The Space Act "provided for research into the problems of flight within and outside the earth's atmosphere." The Soviet Union had an established space program at the time, and had already launched Sputnick I and Sputnick II, in 1957. The United States followed suit by launching JPL's Explorer I satellite in January of 1958. The space race was on.

Initially, space was the domain of governments and government contractors. Private investment in space appeared to be unreasonably risky, as the return on investment in space was basic scientific knowledge, aerospace engineering knowledge that primarily had potential applications to national defense, and heroic accomplishments that fueled national pride.

The first private investments in space were communication satellites. Arthur C. Clarke (the science fiction writer), at the age 27 as an Officer in Royal Air Force, proposed that a satellite at 22,236 miles above the Earth's surface would remain at a fixed point above the Earth, moving at the same speed as the Earth, which would be ideal for in-space radio communications [2]. The orbit that Arthur C. Clarke described is now known as a geosynchronous orbit, or GEO. On December 18, 1958, the Air Force's Project SCORE launched the first communications satellite that transmitted human voice, relaying a taped message from Dwight D. Eisenhower stating "Peace on earth and goodwill toward men everywhere". John F. Kennedy initiated the creation of the International Telecommunications Satellite Organization (INTELSAT) in a speech to the United Nations on September 25, 1961, and later signed the U.S. Communications Satellite Act of 1962. The first commercial communications satellite was the Intelsat I (nicknamed "Early Bird"), built for the Communications Satellite Corporation by Hughes. Intelsat I was launched in 1965 and operated in a GEO orbit. Intelsat I demonstrated the viability of communications in GEO, and assisted with the first live TV coverage of the Gemini 6 splashdown in December 1965.

978-1-7821-2734-7/20/$31.00 ©2020 IEEE

The 1967 Outer Space Treaty – Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies [3] - was the first international treaty that governed the use of space resources and forms the basis for international space law. Some of the concepts in this treaty were modeled on the Antarctic Treaty, and there are now 109 countries that are parties to this treaty. The treaty prohibits the placing of nuclear weapons in space, it limits the Moon and terrestrial bodies to peaceful purposes, and provides for the "non-appropriation of space", according to which outer space is "not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means." The Outer Space Treaty does, however, establish the principle that the state of registration has jurisdiction and control over space objects as well as personnel launched into outer space.

Not surprisingly, the Soviet Union wanted space to be controlled by governments, while the United States wanted to allow for private enterprise in space. This, as we shall see, became a recurring theme in developing space law and business, as the United States continued to pass laws to liberalize the utilization of space by private enterprise.

COMSAT (Communications Satellite Corporation) was formally established as a result of the Communications Satellite Act of 1962 [4], which charged COMSAT with responsibility for developing a commercial communications satellite system. In 1964, COMSAT helped create and was majority owner in INTELSAT. By 1970, COMSAT formally began an enterprise: owning and operating Earth stations in other countries. In 1973, COMSAT formed a new subsidiary, COMSAT General, for "domestic satellite programs and other new business opportunities". Marisat-1 was launched in 1976. In 1980, COMSAT launched Satellite Business Systems (SBS) in partnership with IBM/Information Satellite Corporation, and Aetna.

On the European front, the European Space Agency formed Arianespace in 1980 as the first commercial launch services provider for the purpose of launching commercial satellites into GEO orbits using its family of Ariane launch vehicles. Initial hardware and launch facilities were developed with government funding. By 1997, Arianespace had launched 100 satellites. Arianespace SA is in operation today, and is a now multinational company that serves as the marketing and operation of the Ariane program, and has launched over 550 satellites. Also in Europe, OTRAG (Orbital Transport und Raketen AG) was formed in Stuttgart Germany as the first commercial developer and producer of space launch vehicles. A full orbital launch vehicle was never assembled, however, and the German minister of foreign affairs at that time (Hans Dietrich Genscher) halted the project and joined Arianespace.

On 30 October 1984, Ronald Reagan signed the Commercial Space Launch Act [5]. This Act states: "the peaceful uses of outer space continue to be of great value and to offer benefits to all mankind: private applications of space technology have achieved a significant level of commercial and economic activity, and offer the potential for growth in the future". The Act explicitly recognized the role of the private sector in space, also stating: "the private sector in the United States has the capability of developing and providing private satellite launching and associated services that would complement the launching and associated services now available from the United States Government". This enabled an American industry of private operators of expendable launch systems. Prior to the signing of this law, all commercial satellite launches in the United States were restricted by Federal regulation to NASA's Space Shuttle.

Perhaps the most sweeping law to encourage commercial space was the Commercial Space Act of 1998 [6]. The purpose of the Act was stated plainly: "To encourage the development of a commercial space industry in the United States, and for other purposes". The Act contains 1990's optimism for the invisible hand of the free market in allocated and exploiting space resources, stating: "The Congress declares that a priority goal of constructing the International Space Station [its first component launched on November 20, 1998 and occupied by humans on November 2, 2000] is the economic development of Earth orbital space. The Congress further declares that free and competitive markets create the most efficient conditions for promoting economic development, and should therefore govern the economic development of Earth orbital space. The Congress further declares that the use of free market principles in operating, servicing, allocating the use of, and adding capabilities to the Space Station, and the resulting fullest possible engagement of commercial providers and participation of commercial users, will reduce Space Station operational costs for all partners and the Federal Government's share of the United States burden to fund operations."

Six years later, the Commercial Space Launch Amendments Act of 2004 [7] was passed. Importantly, this act permits private manned space flight. With a permit and proper training, it allowed a private company to launch or reenter crews, to launch or reenter a space flight participant, and launch and reenter crews and space flight participants in accordance with regulations and applicable laws. This, of course, paved the way for employees of private companies to conduct operations in space, and for space tourism.

Even in 2004, true commercial space was just getting off the ground. Blue Origin was founded on September 8, 2000 by Jeff Bezos, and SpaceX started on May 6, 2002 by Elon Musk. Small venture capital funded startups were very rare, however, but as space launch prices dropped, and new technologies that had applications for commercial space became recognized, venture capitalists started becoming aware of opportunities.

As the privatization of space progressed, and especially as small companies and startups entered into the business financed by venture capital, the importance of intellectual property grew. Smaller firms do not have the capital barriers to entry that large firms have such as Blue Origin and SpaceX have, and require intellectual property assets to protect their business in order to attract investment.

2. Intellectual Property in the Business of Space

Introduction to Intellectual Property

Intellectual property is property that is legally created from the intellectual effort of a person. Typically, intellectual property that results from research and development takes the form or patentable inventions, computer software, or know-how. Examples of know-how are drawings designs, preferred embodiments, methods, testing, materials, schematics, netlists, and/or tacit knowledge. A software copyright is the exclusive right to the expression or creative work in a software program, although it does not protect the method or mechanism of action that the software carries out. In other words, several different copyrighted software programs can perform the same method and produce the same results. Copyright protection is construed relatively narrowly compared to patent protection, but the upside is that the copyrights are granted automatically under the law – software is copyrighted upon creation, so no legal expense involved. The owner of the software has exclusive rights to make and sell copies (one can think of copyright as the right to copy), make derivative works based on the original software, perform/display the software, and license the software.

A patent is the right to exclude others from making, using, selling, or importing a patented invention. A patent in the United States may be awarded for a new, nonobvious, and useful compositions of matter, methods, machines, articles of manufacture, or new applications of existing technologies. The United States Patent and Trademark Office examines patents to determine whether or not they claim patentable subject matter, and that what the patent claims as a new invention is new and nonobvious in light of any existing publications, patents, or available products anywhere in the world. If an inventor is the first to innovate in an area, that inventor may be able to achieve very broad foundational patents that cover large portions of the new technology. For example, JPL was an early innovator in complementary metal oxide semiconductor (CMOS) imaging technology, and filed patent technology in the early 1990s when the commercially employed technology was charge coupled devices (CCDs). One application for which CMOS imaging was useful was in space due to CMOS's low power requirements and compactness. CMOS imaging was a very difficult technical challenge, and with the commercial availability of CCDs, there was very little research in the topic at the time that JPL initiated its research. As a result, JPL obtained very broad patents because the patent office had few publications, patents, and no products to narrow JPL's claims to the technology. Present research in CMOS imaging now produces, understandably, much narrower patentable coverage.

Importantly, patents have a limited lifetime, and typically expire 20 years after filing. In the case of CMOS imaging, the JPL researchers were so far ahead of their time that the market for CMOS imagers (primarily in cell phones) peaked after the patents expired.

The economics of patents are typically dominated by the cost of obtaining a patent or asserting the patent (through litigation, for example) versus the benefits, which includes having a certain amount of control over an area of technology for a limited period of time. The legal cost is significant enough such that individuals and companies typically file for patents only because they believe that the patents will protect their business from competitors, or if they believe that the patents will pay off in terms of business partnering or litigation. Companies may also file "defensive" patents, which they believe could be useful if a competitor asserts a patent against them, so they can then assert their own patents against the competitor.

Intellectual Property in Space

So, if an inventor obtains a patent for an invention, and someone infringes the patent in outer space, is there anything that the inventor can do? The answer is yes, and the legal authority can be found in United States law 35 USC 105. [8] An invention "made, used, or sold in outer space or component thereof under the jurisdiction of the United States shall be considered to be made, used, or sold within the Unites States". The United States is the only country that has enacted such a law, so if the invention is under the jurisdiction of another country, the patentee is out of luck unless they can show that the invention was made, used, sold, or imported into the United States before it went into space. Fortunately, the United States is more commercially active in space that any other country, which we shall see later. In addition, the Outer Space Treaty requires that all spacecraft be registered with a national government and to the United Nations. In the United States, the Federal Aviation Administration Office of Commercial Space Transportation regulates and licenses non-government spacecraft under the Commercial Space Launch Amendments Act, so it would be impossible for an infringer making a commercial spacecraft in the United States to not fall under United States jurisdiction.

3. University Technology Transfer

So, where do universities fit into all of this? On December 12, 1980, Jimmy Carter signed into law the Bayh-Dole Act [9]. This law allowed recipients of federal research contracts such as universities, research institutions, and small business, to elect title to federally sponsored research.

Prior to the Bayh-Dole Act, the federal government had increased spending on scientific research, which led to over 28,000 federally owned patents, but only 5% of them were licensed for commercial use. Universities and research institutions now had the right to file patents on the results of federally sponsored research, including research that resulted in new space technologies. In addition, the Federal Acquisition Requirements (FAR) allowed federal contractors to take title and license copyrights to computer software, and federal research contracts allow contractors to license various forms of know-how as well. Universities are now empowered to license the patents, software, and know-how to commercial space companies, enabling new companies to have a competitive advantage in the commercial space market such that private investments can be made such that the public may benefit from the technology.

Universities and their federal laboratory operating divisions perform research in space related topics and often times produce valuable intellectual property of all types that can benefit the commercial space industry. Universities performed $68.2 billion in research in 2017, generating 24,998 new technology disclosures that were submitted to university technology transfer offices [10]. For software technology, decisions are relatively easy because, as we have noted, software is copyrighted upon creation at no cost. For patents, it is a different matter. Universities are not in the business of making, using, and selling the technologies that arise from their research, so they must license the technology to a private company to realize the benefits of their patents. In addition, if the technology was funded by any agency of the U.S. Government, the U.S. Government has a free right to make, use, and have the patented products made by their contractors. Therefore, a technology that only has use for the U.S. Government would not be patented by a university. Technology transfer professionals must make a cost/benefit decision based on the high legal expenses of obtaining a patent versus the benefits of licensing the patent commercially.

University license agreements are normally royalty bearing or fee based, and often times include a small share of equity in the case of startups. Equity is normally taken by universities in lieu of an up-front license fee, and dilution protection is negotiated.

Typical factors that determine royalty rates and fees are the:

- Available alternatives to the technology and the cost to the licensee of those alternatives;
- Value of the intellectual property protection (How well does the intellectual property protect the business of the licensee? How easy is it to design around the patents or software copyrights? What are the odds of the patent being issued given the prior art?)
- Cost of patent protection and the ability to enforce the intellectual property right;
- Level of development of the technology being licensed (required R&D and tooling investment by licensee); and
- Time to market.

The royalty rate would be multiplied by revenues of the product covered by the intellectual property, so the larger the revenues, the larger the total royalty. A lump sum royalty would necessarily involve some crystal balling, as the future revenue of the products covered by the intellectual property can be very speculative.

Prior to 2009, inventions with applications solely for space were formerly considered to have little value, patentable or not, because the market for early stage university technology is with small companies and startups. The economics of technology adoption in the United States is such that startups and small companies develop early stage technologies, and larger companies then purchase the small companies, and investors in the small companies hopefully achieve a risk adjusted return on investment. In 2017, 70% of university licenses went to startups and small companies [10]. In addition, space technologies were typically practiced by the U.S. Government or their U.S. Government contractors, who already had a license incorporated into the Bayh-Dole legislation. Even for technologies for non-government use, JPL's licensing history indicated that large aerospace companies were unlikely to license and invest in early stage technology until the licensed technology was at a very high technology readiness level. As a result, Caltech, like many universities, routinely passed on electing title to and patenting space technology unless it had applications on earth, such as CMOS imaging, GPS, or robotics.

4. The Rise of Commercial Space

Since 2009, however, things have changed dramatically for licensing space technologies. This has been due to a number of factors including new technologies such as:

- New satellite options - Smallsats, Nanosats
- Communication technologies (miniaturization, data capacity, form factors)
- Imaging/camera technologies
- Global Positioning System (GPS)
- New propulsion technologies
- Lower cost launches, and more launch options

In addition, there are business factors that include:

- New industries that benefit from space-based products (internet, space tourism, imaging, weather, GPS, environmental monitoring)
- Governments, especially the Unites States, that do not wish to compete with the private sector, and would prefer to be buyers of services and data acquired in space rather than producers of such services and data

- Large amounts of private risk capital (primarily venture capital) that became available for commercial space startups.
- Increasing numbers of startups and small companies in the commercial space realm

There is no firm economic model of exactly what sent forth a flow of venture capital, angel capital, private equity, and other forms of private capital around this time, except to say that the above factors were all in place simultaneously, and the market forces and excitement in the opportunities of commercial space took hold.

Privately funded startup companies – large and small – were and continue to be powerful influences in the new commercial space age. Startups such are more focused on changing existing paradigms, disrupting status quo business models, and developing entirely new products and services than very large companies. Startups are also under tremendous pressure to make their new products and services succeed because they have no legacy business to fall back on. In addition, many of the commercial space startups were extremely well funded. SpaceX and Blue Origin received vast amounts of funds from their founders Elon Musk and Jeff Bezos. Other startups such as OneWeb ($3 billion), RocketLab ($215 million), SpaceFlight Industries ($215 million), and Arieon ($119 million) were also well funded with private capital [11].

Investment Type	Total 2000-17 (millions)	Average 2000-17 (millions)
Seed/Prize Grant	2,292.8	127.4
Venture Capital	6,295.3	349.7
Private Equity	1,743.3	96.8
Acquisition	3,582.3	199
Public Offering	23.4	1.3
Total Investment	13,937.1	774.2
Debt Financing	4,482.2	249
Total with Debt	18,419.3	1023.2

Table 1. Cumulative equity investments in commercial space totaled $18 billion from 2009 to 2018 (Credit: Bryce and Technology) [11]

Commercial space after 2009 has been classic American entrepreneurial experience. The perception of business opportunities led entrepreneurial wealthy angels to invest in low cost launching businesses, which lowered the cost of doing business in space, attracting risk tolerant entrepreneurs, angels, and venture capital investment in startups. This in turn created an ecosystem of intense value creation in a new and growing field. Over $18 billion has been invested in commercial space since 2009 from a variety of sources, primarily venture capital [11]. There are now hundreds of venture funds that have invested in commercial space, and hundreds of new commercial space companies are now vying for new opportunities.

The sheer number of venture capital funds investing in commercial space has risen dramatically as well. In 2009, there were only a handful of venture capital firms that had the capital and stomach for risk to invest in commercial space, including Draper, Kleiner Perkins, New Enterprise Associates, and Norwest Venture Partners. By 2019, the number of cumulative firms investing in commercial space rocketed to 750, including many boutique venture funds that invest in targeted technologies and business opportunities, offering entrepreneurs greater choices in securing much needed financing (Space Angels [12]).

The Internet in Space

The internet is arguably the most important factor driving the largest investments in commercial space. Now thought of as ubiquitous in the developed world, the internet is a network of networks that consists of private, public, academic, business, and government networks of local to global scope, linked by a broad array of electronic, wireless, and optical networking technologies.

The internet is an excellent example of a project that was initiated by federal government of the United States (ARPANET) and then handed off to the private sector. The use of the internet grew in the 1980s with private funding and increasing support from other federal scientific agencies such as the NSF, but it exploded in the 1990s when commercial networks and enterprises linked to it.

For commercial space, the increasing reliance on the internet in human affairs all over the globe has profound implications. There is a perceived need for global access to the internet similar to electricity, water, and global positioning systems, in which a constellation of satellites is necessary to provide global internet availability. As we will see below, the greatest number of planned smallsats is for global and reliable internet access.

SmallSats and CubeSats

Another technology whose adoption has propelled commercial space investment has been the miniaturization of spacecraft design. Large and medium satellites (500 kg to over 1000 kg) are generally being replaced with small satellites (smallsats). Smallsats generally fall under the categories of minisatellites (100-180 kg), microsatellites (10-100 kg), nanosatellites (1-10 kg), picosatellites (0.01-1 kg), and even and experimental classes called femtosatellites (0.001-0.01 kg), attosatellites (1g-10g), and zeptosatellites (100 mg to 1 g).

CubeSats are modular satellites, and typically fit into the nanosatellite category. They are, by far, the most common type of nanosats launched, and are comprised of units of "1U" measuring 10x10x10 centimeters. CubeSats sizes range from 0.25U to 27U. 1088 CubeSats have been launched as of June 2019, and it is expected that hundreds more will be launched each year.

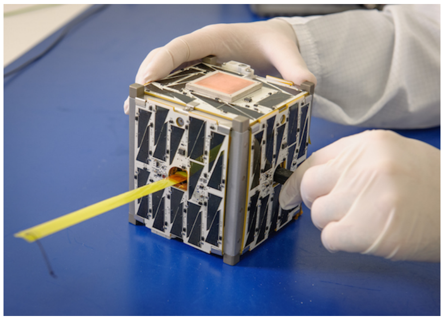

Fig. 1: One unit (1U) CubeSat (Credit: NASA Ames)

CubeSats were developed by universities, originally at California Polytechnic State University at San Luis Obispo and Stanford University, as an affordable way to provide students with hands-on experience in aerospace engineering without the extreme cost of dealing with conventional satellites. Bob Twiggs at Stanford, one of the earliest innovators of Cubesats, stated: “It was developed for the education of students. If you make it small, they can't put much in it, so they get it done quicker, and hopefully you can get it launched for a lot less money. I don't think Jordi Puig-Suari at Cal Poly or myself had any idea that we'd see days like this.” [13]

Indeed, CubeSats have come into the mainstream of spacecraft. Two MarCo CubeSats that were employed in the JPL’s successful Mars Insight mission were the first to be used in deep space.

CubeSats are both enabled by new technology, and enable new technology. CubeSats are practical spacecraft because they are enabled by new miniaturized electronics, power supplies, computing, cameras, radios, antennas, and radar. CubeSats enable new technology because they are compact, inexpensive, and can be loaded with instruments that enable new science missions and technological achievements at lower cost.

Global Positioning System

The Global Positioning System (GPS) is a satellite-based system owned by the United States government and operated by the United States Air Force, using a global navigation satellite system that provides geolocation information anywhere on the earth where there is line of sight with at least four GPS satellites. The first prototype spacecraft launched in 1978 and the full constellation of 24 satellites was operational in 1993. The Russian Global Navigation Satellite System became fully operation in the mid-2000s. China's BeiDou Navigation Satellite became operation in for global positioning in 2018, with full deployment scheduled for 2020. In addition, the European Union (Galileo), India (NAVIC), and Japan (QZSS, to augment GPS in Oceana schedule for 2023)) all have systems as well. The global positioning systems (GPS) market size was estimated at $37.9 billion in 2017, and is still expected to grow rapidly due to increasing applications for smart phones, transportation, and geolocation marketing [15].

GPS has important implications for in-space technology because the same signals that provide for positioning services for vehicles on earth can also be used to position, track, and predict orbit trajectories for satellites in space, as we shall be below.

5. Examples of Licensed Technologies

Several examples of technologies that Caltech/JPL has licensed will be illustrated as examples of commercial space licensing.

MaSMi Hall Thruster Technology

Thruster technologies have historically been the domain of very large aerospace companies and governments, primarily concerned with launching spacecraft and cargo past escape velocity so that they can enter into outer space. Hall thrusters and other ion thrusters that are employed after the spacecraft is already in space will likely become an increasingly important commercial space technology. A Hall thruster is a type of ion thruster in which the propellant is accelerated by magnetic field. The first Hall thruster to operate in space, an SPT-50 aboard a Soviet Meteor spacecraft, was launched December 1971, and were mainly used for satellite stabilization, and over 100 SPTs were launched in the next 20 years. In the 1990s, researchers from JPL, Glenn Research Center, and the Air Force Research Laboratory visited Russian laboratories and experimentally evaluated the SPT-100, and began developing their own Hall thruster designs.

Hall thrusters and other forms of ion thrusters are expected to play an important role in satellite positioning, station-keeping, acceleration and deacceleration, orbit trajectory, and in thrusting satellites into new orbits (from LEO to GEO, for example) as large constellation of satellites are deployed over the next decade. There are now several small innovative companies in the Hall thruster space.

One problem with the use of Hall thrusters in the commercial space context is the primary life-limiting effects of erosion of the thruster channels due to ion bombardment and thermal heating causing high-energy electron power loss to the channel. These effects reduce a thruster's performance during operation and yield a reduction in the thruster's useful life.

JPL made significant advances in creating technology that magnetically shields Hall thrusters to prevent erosion. After decades of development, JPL engineered a Hall thruster with optimized magnetic shielding that provides very efficient power levels over a very broad range of thrust levels (55 mN of thrust and 2 MN-s total impulse, 55 MN/kW thrust-to-power). The new thruster is called the Magnetically Shielded Miniature, or MaSMi, Hall thruster technology.

JPL has nonexclusively licensed its MaSMi thruster technology to Apollo Fusion, a startup company in Silicon Valley. Apollo Fusion plans to use the MaSMi technology in an electric thruster called the Apollo Xenon Engine (AXE).

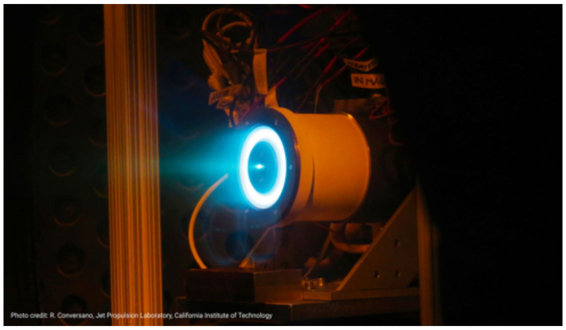

Fig. 2. JPL MaSMi Hall thruster in operation. Credit: California Institute of Technology

Ka Band Deployable Antenna

RF engineers at JPL were challenged with designing a low-cost antenna that could fit on a cubesat architecture, deploy reliably in space from a folded launch position, and operate at a frequency and gain that would be scientifically useful. The engineers designed a 0.5 meter Ka-band parabolic deployable antenna (KaPDA) which would stow in 1.5U (10 x 10 x 15 cm^3) and provide 42dB of gain (50% efficiency). A folding rib architecture and dual reflector Cassegrainian design was selected, as it best balances RF gain and stowed size. The design implements an innovative telescoping waveguide using a powered screw mechanism or gas powered deployment. The antenna flew on the JPL RainCube (Radar on a CubSat) mission, and exhibits 42 dB of gain.

The patent [16] and know-how for the deployable antenna were licensed to Tendeg in Louiseville, CO. Tendeg is offering a commercial version of the antenna, and is making modifications to the subreflector and feed antenna so that is can operate in C, X, Ku, K and Q bands.

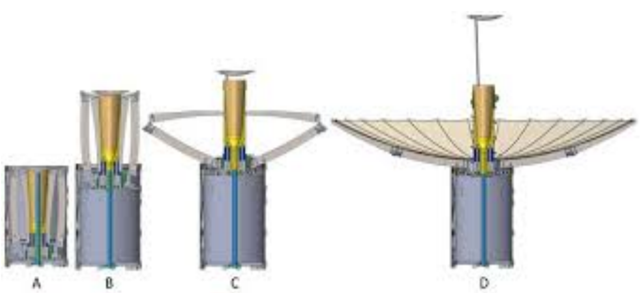

Fig. 3. Unfolding of CubeSat compatible Ka-band space deployable antenna from its compact position in a cylindrical container Credit: Jet Propulsion Laboratory

GPS Radio Occultation and Gravity Mapping

JPL has significant expertise in radio occultation and gravity mapping. A constellation of six Cosmic II satellites were recently launched and successfully deployed to measure the changes in GPS radio signals as they pass through the atmosphere. The changes to the GPS signals can the be used to infer atmospheric weather conditions.

JPL is now working with two small companies, GeoOptics (headed by Tom Yunck, a former JPL employee) and Tyvak, to miniaturize and commercialize GPS radio occultation. GeoOptics intends to launch a constellation of cubesats that employ GPS radio occultation and other techniques to measure global weather patterns thousands of times per day. The new business model is that the radio occultation data will be then sold to the U.S. government rather the government employing contractors to build and launch RO satellites.

Data Visualization

Much of the data that is collected in science, healthcare, defense, and business could be made much more valuable if there is a way to visualize the important aspects of the data so as to gain a greater understanding of its meaning. Caltech astronomer George Djorgovsky and JPL visualization engineer Scott Davidoff formed a startup company called Virtualitics to provide data visualization services to industry and government customers.

Virtualitics licensed a Caltech patent [17] that claims a data visualization system for generating 3D visualizations of a multidimensional data space. The data can be visualized in a virtual room with several people present in different locations in the room to view, discuss, and analyze the visualized data.

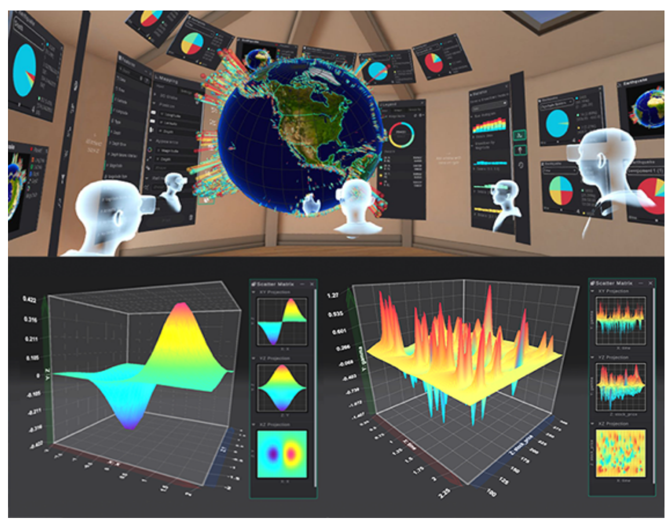

Fig. 4. Virtual room with several analysts (potentially in different locations) of visualized data Credit: Virtualitics

Satellite Tracking and Positioning Software

There are now plans to deploy tens of thousands of satellites over the next ten years. SpaceX has requested the International Telecommunication Union to arrange a spectrum of up to 42,000 Starlink satellites. Amazon has just filed an application with the Federal Communications Commission (FCC) to launch its constellation to provide broadband internet anywhere on Earth. In addition, there are plans by LeoStat, Telestat, 02b and CASIC to launch and deploy satellite constellations. Given the size of the constellations, there is a high demand for technology to provide positioning, station-keeping, tracking, orbit trajectory, and ground truthing on order to optimize the effectiveness of the constellation.

Several technologies developed at JPL to track JPL's constellation of satellites have proven to be very valuable to commercial space operations. JPL's GIPSY-OASIS software is the GNSS-Inferred Positioning System and Orbit Analysis Simulation Software package. The current system, called GipsyX, is now being deployed by several commercial firms for airplane positioning and precise orbit determination, with GNSS constellations such as GLONASS. In addition, JPL has licensed a real time version called RTGx (Real Time Gipsy).

About 50 miles above the Earth's surface, electrons can be separated from atoms, resulting in positive ions and free electrons. GPS and other radio signal delays caused by activity in the ionosphere are measured in meters, with large delays being on the order of 40 meters, interfering with ground truthing. JPL's Global Ionospheric Mapping (GIM) software packages, SuperTruth and IonoSTAGE packages allow systems to address the threat to accurate positioning posed by code delays and phase advances due to refraction in Earth's ionosphere. More recently, the continued development of Wide Area Augmentation System, a system used in commercial airliners for navigation and landing assistance, has relied on such software developed at JPL to improves the accuracy, availability, continuity, and integrity of GPS positioning enough to ensure its safe use by pilots to determine their locations.

Fig. 5. Global Positioning System (GPS) satellites, such as this one from the Block IIR series, not only transmit data to and from GPS units on earth, but they are also used to determine the extent to which those signals are being delayed by activity in Earth's ionosphere. Credit: Jet Propulsion Laboratory

Gecko Grippers

Research at Stanford University that continued at JPL resulted in patented grippers [18] that utilize Van der Waals forces. This technology was named "gecko grippers" because the feet of gecko lizards also use Van der Waal forces. Van der Waal forces arise where a slight electrical field is created because electrons orbiting the nuclei of atoms are not evenly spaced, so there are positive and negative sides to a neutral molecule (as in hydrogen bonding). The positively charged part of a molecule attracts the negatively charged part of its neighbor, resulting in attractions that can be employed to grip objects.

There are several advantages to this gripper technology. There are no pneumatics, hydraulics, or adhesives necessary for gripping, and the grippers work in extreme temperature, pressure and radiation conditions. The newest generation of grippers can support more than 150 Newtons of force, the equivalent of 35 pounds (16 kilograms).

In a microgravity flight test, the gecko-gripping technology was used to grapple a 20-pound (10 kilogram) cube and a 250-pound (100 kilogram) person. The gecko material was separately tested in more than 30,000 cycles. Despite the extreme conditions, the adhesive stayed strong. Researchers have more recently made three sizes of hand-operated "astronaut anchors," which could one day be given to astronauts inside the International Space Station.

The gecko gripper technology was licensed to Perception Robotics, a small startup that was at that time in the Los Angeles Cleantech Incubator at the time the technology was licensed. Perception Robotics was then purchased by OnRobot A/S, with Perception Robotics still now operating as a subsidiary in Los Angeles. In addition to potential applications in spacecraft, the gecko gripper is very useful in manufacturing processes for gripping to smooth objects in cases where the use of hydraulics and pneumatics are costly and cumbersome.

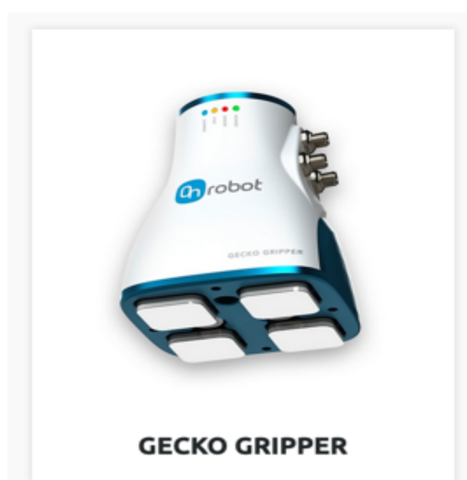

Fig. 6. Commercial version of On Robot's Gecko Gripper Credit: OnRobot A/S

Mission Analysis and Navigation Software

JPL recently made its Mission Analysis, Operations, and Navigation Toolkit Environment (MONTE) available for license after using JPL software innovation funds to make the user interface friendlier. MONTE is an astrodynamics computing platform that supports all phases of space mission development. MONTE includes Cosmic and general trajectory optimization, trajectory differential corrector, launch contour analysis tool, horizons small body ephemeris interface, a 3-D trajectory viewer, and a landing sites tool. The MONTE software is available in two forms, the Design Edition for basic mission design, and a full version for in-depth mission design and plan. MONTE has been licensed to several academic institutions and commercial space companies. More information on MONTE may be found at https://montepy.jpl.nasa.gov/static/document/brochure.pdf.

Iris V2 CubeSat Transponder

Communications systems will be an increasingly important facet of commercial space technology, and in-space communication systems are becoming a competitive market, with new niches being addressed. JPL designed the Iris deep space small satellite radio as a software-defined telecommunications subsystem designed specifically for orbits beyond LEO, such as MEO, GEO, Lunar, and interplanetary missions. Iris uses an environmentally robust architecture, including radiation-tolerant parts needed for deep space, multi-year missions. The design incorporates advanced thermal management needed for navigation tracking sessions of several hours. In addition, the Iris transponder is CubeSat/SmallSat compatible, weighing only 1.1 kg and using 35 watts of DC power at 3.8 watts radio output power.

Caltech licensed the Iris transponder to the Space Dynamics Laboratory (SDL), and SDL has supplied JPL with the transponders for its mission purposes. SDL is now offering the Iris transponder for sale commercially.

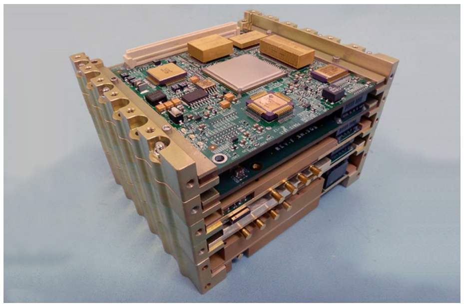

Fig. 7. Iris deep space transponder, capable of X, Ka, S-band, and UHF communications.

6. Challenges and Opportunities for Space Startups and Universities

As a new participant in a legacy industry, new commercial space companies would benefit by becoming acquainted with universities that have important technologies that would give them a competitive advantage, make their business more valuable, and/or increase their attractiveness as acquisition targets. To maximize the probability of success, space companies should target key technologies and researchers that fill gaps and resonate with the strengths of their personnel, investors, resources, and business strategy.

Typical issues to be addressed in many licensing situations are exclusive versus nonexclusive licenses, equity, conflict of interest issues with the researchers, and understanding the business value the of the specific technology and intellectual property available for license. The most important interactions, however, will be with the researchers on both sides.

For universities, it is important to maintain close relationships with their faculty, researchers, the entrepreneurial community, and investors, and to offer as much support as possible to entrepreneurial researchers. Caltech, for example, has hired two Entrepreneurs in Residence (EIRs) in its Office of Technology Transfer and Corporate Partnerships. One EIR focused on life sciences and the other on physical sciences and engineering. EIRs are successful entrepreneurs that have extensive startup experience through exit (IPO or acquisition), and are looking for their next entrepreneurial opportunity. Both of Caltech's EIRs have excellent education and experience in business and technology, extensive involvement in all phases of startups (including exits), and far reaching networks with the entrepreneurial community. The EIRs are especially helpful with preparing researchers before meeting with venture capitalists or other business partners.

Universities should also establish very good relationships with several venture capital firms. This will prove invaluable in terms of feedback, funding, and relationships with their EIRs, entrepreneurial researchers, and future partners.

A particularly vexing issue for many universities and federal laboratory technologies is that, with rare exception, their technologies require significant investment at the time of licensing in order to achieve commercial reality. The involvement of the researchers is highly beneficial in the early stages of the technology handoff and the initial development of the licensed technologies. University professors are often times able to enter into research and consulting agreements, but their federal laboratory counterparts have very high, sometimes insurmountable, hurdles in terms of conflict of interest and freeing up laboratory resources to move licensed technologies forward in a timely manner. Conflicts of interest are understandable challenges for federal labs, and it is suggested that, rather than categorizing situations and concluding that a conflict exists (e.g. the researcher wishes to consult while engaged in an active program in the lab), that conflicts are specifically identified. Reasonable questions are: Why specifically, for example, would consulting with a licensee conflict with the researcher's ability to perform research in the laboratory? Is there an identified conflict, and one that can be managed and mitigated?

7. SUMMARY

Challenges and opportunities for universities, federal labs, researchers, and commercial space companies must be met cooperatively and head-on in order for the United States to realize the full potential of its technological prowess in the commercial space realm.

ACKNOWLEDGEMENTS

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004).

I would like to thank Brendan Serapiglia for his insights in space laws and treaties.

DISCLAIMER

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.

REFERENCES

[1] National Aeronautics and Space Act of 1958, Public Law #85-568, 72 Stat. 426 H https://history.nasa.gov/spaceact.html

[2] Arthur C. Clarke, "Extra-Terrestrial Relays: Can Rocket Stations Give Worldwide Radio Coverage?"

[3] United Nations Treaties and Principles on Outer Space, United Nations, New York, New York, 2002, https://www.ifrc.org/docs/idrl/I515EN.pdf

[4] Communications Satellite Act of 1962, Public Law 87-624

[5] H.R. 3942 Commercial Space Launch Act, 98th Congress (1983-1984) https://www.congress.gov/bill/98th-congress/house-bill/3942

[6] Commercial Space Act of 1998, Title II – P.L. 105-303 https://www.nasa.gov/offices/ogc/commercial/CommercialSpaceActof1998.html

[7] H.R. 3752 – Commercial Space Launch Amendments Act of 2004, 108 Congress (2003-2004 https://www.congress.gov/bill/108th-congress/house-bill/3752

[8] U.S. Code Section 105. Inventions in Outer Space https://www.law .cornell.edu/uscode/text/35/105

[9] U.S. Code Chapter 18 – Patent Rights in Inventions Made with Federal Assistance (also know as the Bayh-Dole Act), Sections 200 – 212 law.cornell.edu/uscode/text/35/part-II/chapter-18

[10] AUTM 2017 Licensing Activity Survey, Oakbrook Terrace, IL https://autm.net/AUTM/media/SurveyReportsPDF/AUTM_2017_US_Licensing_Survey_no_appendix.pdf

[11] Bryce Space and Technology, "Start-Up Space: Update on Investment in Commercial Space Ventures", 2018

[12] Space Angels, "Space Investement Quarterly", Q4 2018

[13] Stephen Clark, "A Chat with Bob Twiggs, father of the Cubesat", SpaceFlight New, posted March 8, 2014

[14] Erik Kulu, Nanosatellite & CubeSat Database" https://www.nanosats.eu

[15] Grand View Research, "Global Positioning Systems (GPS) Market Size, Share & Trends Analysis by Deployment, by Application (Aviation, Marine, Surveying, Location-Based Services, Road) and Segment Forecasts, 2018-2015", Published Date: October 2018

[16] Patent 10, 170, 843 titled "Parabolic Deployable Antenna" issued January 1, 2019

[17] Patent 9,665,988 titled "Systems and Methods for Data Visualization Using Three Dimentional Displays", issued May 30, 2017.

[18] Patent 9, 517,610 titled "Grippers Based on Opposing Van der Waals Adhesive Pads", issued December 13, 2016

BIOGRAPHY

Dan Broderick *is the Manager of the Office of Technology Transfer at JPL. Prior to JPL, he was the Associate Director to the Office of Technology Transfer at the California Institute of Technology, and of Director of the Office of Technology Transfer and Commercialization at the University of Michigan College of Engineering. He has worked as an electrical engineer at Motorola, as a manager of electrical engineering at Rockwell International, and has been involved in several startup companies as well. Dan received his Bachelor of Science in Engineering at the University of Michigan, his Masters Degree in Electrical Engineering and Computer Science at Northwestern University, and his MBA at the University of Chicago.*